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Surface electromyography (sEMG) biofeedback posture training improves the physical and mental health of early adolescents with mild scoliosis: A qualitative study

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Abstract

Introduction: Asymmetry in paraspinal muscle activities is observed in adolescent idiopathic scoliosis and may be of value for predicting curve progression. We have reported the effects of the surface electromyography biofeedback posture training program in improving the symmetry of paraspinal muscle activities and reducing the curve progression of early adolescents with mild scoliosis. This study further explored their subjective experience of the training program on posture correction and health-related quality of life.

Methods: Using purposive sampling, 13 early adolescents aged between 11 and 13 years with mild scoliosis participated in semi-structured in-depth interviews after completing 30 sessions of training. The data were recorded, transcribed, and coded using thematic analysis with NVivo 10. Significant statements and phrases were categorized into themes and subthemes.

Results: As assessed by X-ray, five early adolescents showed at least a 5° Cobb angle reduction in spinal curvature, while eight showed no significant curve progression (a Cobb angle change under 5°). Several subthemes related to the benefits of the training program on the health-related quality of life were generated, namely (a) posture correction, (b) improvement in body appearance, (c) restoration of muscle relaxation, (d) reduction in bodily pain and fatigue, (e) enhancement of self-confidence/self-image, and (f) improvement in social functioning.

Conclusions: Given its positive effects, the sEMG biofeedback posture training program has the potential to be an alternative early intervention for early adolescents with mild scoliosis. Further empirical studies need to be carried out to substantiate its effectiveness and evaluate the sustainability of its benefits over time.

Keywords

Adolescent idiopathic scoliosis, surface electromyography biofeedback posture training, mild scoliosis

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Background

Adolescent idiopathic scoliosis (AIS), the most common type of spinal deformity in the pediatric population, is characterized by uneven shoulders, a back hump, and an unlevel pelvis. As suggested by most studies,[1] the prevalence of AIS is around 2% to 3%. It is more common in females than in males,[2–4] with mild scoliosis (i.e. a spinal curvature angle or a Cobb angle between 10° and 20°) accounting for around 90.5% of cases.[4] Mild scoliosis is generally asymptomatic. Although most cases (around 80% to 90%) are non-progressive,[5] the remaining adolescents are at risk of curve progression, especially during puberty (aged between 10 and 16 years). In addition, previous studies[6,7] have suggested that adolescents with mild scoliosis have a significantly lower self-image and poorer daily function than age-matched typically developed adolescents. Although they do not suffer from significant symptoms and/or feel significant changes with their spine as compared with those with moderate or severe scoliosis (i.e. a spinal curvature angle or a Cobb angle over 20°), they are also unhappy with their back shape throughout their lives and suffer from more severe back pain than age-matched normal adolescents,[6,7] even when their trunk asymmetry is mild.[8] Therefore, the adverse influence of mild scoliosis on adolescents' health and well-being cannot be overlooked, and early intervention during puberty should be considered to reduce the risk of curve progression and enhance health-related quality of life.[9,10]

While the treatment options for adolescents with moderate or severe scoliosis traditionally include exercises, in-patient rehabilitation, braces, and surgery,[1] those with mild scoliosis only require observation during follow-up through clinical monitoring and re-examination every six months. The choice of early intervention for adolescents with mild scoliosis is relatively limited. Physiotherapeutic scoliosis-specific exercise (PSSE) consists of a program of curve-specific exercise protocols specific to the location of the adolescent's curvature and severity of spinal deformity.[11] This program is an early intervention recommended for adolescents with mild scoliosis, who are taught self-correction and stabilizing exercises, such as balance, neuromotor control, and proprioceptive training,[12] to improve their self-awareness of their spinal deformity.[11] The effectiveness of PSSE, as demonstrated in a systematic review, includes a reduction in the curve progression rate and Cobb angle improvement.[13] Randomized controlled studies of PSSE have further supported the positive effects of PSSE on appearance perception, quality of life, and back muscle endurance.[14–19]

Asymmetry in paraspinal muscle activities is observed in AIS.[20–24] While abnormalities in paraspinal muscle activities are likely to be secondary to spinal deformity,[25] some studies have shown that they may be of value for predicting curve progression.[26,27] Therefore, posture training to improve the symmetry of paraspinal muscle activities may reduce the risk of curve progression of AIS. With this research hypothesis, our previous pilot study[28] examined the use of the 30-session surface electromyography (sEMG) biofeedback posture training program as another line of early intervention for early adolescents with mild scoliosis, aged between 12 and 14 years, to attenuate the asymmetry of paraspinal muscle activities, control curve progression, and reduce spinal deformity over time. The results of our previous pilot study were encouraging: two early adolescents demonstrated a decrease in spinal curvature of 5.7° and 5.6° as measured by three-dimensional (3D) ultrasound imaging, whereas the remaining five early adolescents showed minimal curve progression, with changes in spinal curvature controlled under 5°. However, one of the limitations was that all of the early adolescents were female. In addition, the spinal curvature was measured by 3D ultrasound imaging, instead of X-ray. Although there is cumulative evidence indicating the excellent reliability of ultrasound imaging with a strong correlation to X-ray,[29] ultrasound is not commonly utilized in clinical practice. X-rays are the gold standard assessment tool for Cobb angles, which are the essential metrics for decision-making in AIS treatment.[30] The influence of the sEMG biofeedback posture training program on health-related quality of life was also not investigated. To fill this research gap, this study, which is regarded as an extension of our previous study,[28] aimed to evaluate the benefits of the sEMG biofeedback posture training program in early adolescents with mild scoliosis with a larger sample size of both sexes. Apart from the change in spinal curvature as measured by X-ray, their subjective experience regarding the influence of the sEMG biofeedback posture training program on their posture correction and health-related quality of life was explored using a qualitative in-depth interview approach. We anticipated that, similar to the treatment outcomes of PSSE and our previous pilot study, the sEMG biofeedback posture training program would control or reduce their Cobb angles and improve their health-related quality of life over time.

Methods

Participants

Early adolescents aged between 11 and 13 years were recruited from a school screening program jointly conducted by The Hong Kong Polytechnic University and The Chinese University of Hong Kong between 2020 and 2021. The school screening program was organized either at local primary/secondary schools or at The Hong Kong Polytechnic University. During the screening, an experienced independent prosthetist–orthotist (P&O), who was

blinded to the study's hypotheses, assessed the early adolescents' upper body postures. The assessment included (a) a visual inspection for physical signs of postural asymmetry, including the presence of head tilt, shoulder asymmetry (a high and low shoulder), hip and pelvic obliquity (hip/pelvic tilt), and spinal curvature while the adolescents were in an upright standing position[31]; (b) Adam's forward bend test[32,33]; (c) measurement of the angle of trunk rotation (ATR) using a scoliometer (OSI, Orthopaedic Systems Inc., Hayward, CA, USA).[34] In this study, an ATR ≥5° with one or more observable physical signs of postural asymmetry was suggestive of positive signs of scoliosis.[35] Early adolescents with positive signs of scoliosis further underwent a radiographic Cobb measurement by X-ray, which is the standard procedure used to diagnose and monitor curve progression. Those with Cobb angles between 10° and 20° when standing, as measured by the angle between the two most-tilted spinal vertebrae in the spinal curve assessed by X-ray, were identified as having mild scoliosis. They were then invited to join the 30-session sEMG biofeedback posture training program to improve the symmetry of their paraspinal muscle activities, reduce spinal deformity, and control curve progression over time.

A total of 19 early adolescents with mild scoliosis voluntarily took part in and completed the 30-session sEMG biofeedback posture training program. Informed assent from the early adolescents and informed written consent from their parents for participation were obtained before the training. Only early adolescents who did not receive other interventions during the training period and who were willing to share their subjective experiences associated with the sEMG biofeedback posture training were recruited for in-depth interviews. Using purposive sampling, 13 early adolescents (seven males and six females) were interviewed, and their demographic and clinical information is shown in Table 1. The research was conducted in compliance with the requirements stated in the Declaration of Helsinki. The study protocol was approved by the Survey and Behavioural Research Ethics Committee and the Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee of The Chinese University of Hong Kong.

sEMG biofeedback posture training program

The sEMG biofeedback posture training program was delivered using Thought Technology BioGraph Infiniti software (Montreal, Canada). The early adolescents received 30 sessions of the sEMG biofeedback posture training[28] around once per week, lasting for around eight months in general. However, due to the COVID-19 pandemic, the duration of the whole training program was extended for six early adolescents, varying from 11.1 months to 13.4 months. During the training session, the adolescents were instructed by a physiotherapist to sit in an ideal recommended posture, maintain it, and relax four pairs of paraspinal muscles, namely, the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae, as much as they could for 5 min. Animated indicators representing visual feedback appeared on the biofeedback screen whenever the paraspinal muscle activities and the ratio of the muscle activities between the left and right sides of the four pairs of paraspinal muscles fell below the threshold of specific individualized requirements. This visual feedback aimed to facilitate muscle relaxation of the four pairs of paraspinal muscles and to achieve the symmetry of paraspinal muscle activities. This posture training routine was administered five times in each session, with a 2-min resting period between each time. Each training session lasted approximately 60 min.

In-depth interviews

To explore the early adolescents' subjective experience regarding the influence of the sEMG biofeedback posture training program on their posture correction and health-related quality of life, the early adolescents were invited to attend an in-depth interview after they completed the 30-session sEMG biofeedback posture training program. All interviews were individually conducted in Cantonese, either face-to-face at The Hong Kong Polytechnic University ($n = 4$) or over Zoom ($n = 9$) in the presence of their parents or guardians, between March 2021 and June 2022. They were undertaken by a male PhD researcher (DL), who has over 20 years of experience and advanced training in conducting qualitative research. The interviewer reviewed the relevant literature on biofeedback and scoliosis before the interview. He neither engaged in the training program nor held strong beliefs about its effects. Early adolescents were acquainted with the interviewer at the time of the interview and were aware of his credentials and reasons for doing the interview. No relationships were established prior to or after the interview. To integrate the data with the quantitative research of this study, the interview questions from the in-depth interviews were structured based on the questionnaire used in the quantitative analysis of this study, namely, the Hong Kong version[36–38] of the 36-item short-form health survey (SF-36),[39,40] which explores the physical and mental domains of health-related quality of life (Supplemental Appendix 1). The SF-36 was developed at RAND as part of the Medical Outcomes Study[39] and has been adapted and validated for over 40 populations,[41] and it is commonly used in adolescents,[42,43] with norm references available from 14 populations,[41] including from Hong Kong.[38] The early adolescents were interviewed based on three different dimensions, namely (a) demographic and clinical information, (b) the influence of spine deformity on the physical and mental domains of health-related quality of life, and

Table 1. Demographic and clinical information of 13 adolescents with mild scoliosis.

Participant	Sex	Age at training (years)	Duration of training	Curve type	Cobb angle before training	Cobb angle after training	Change in Cobb angle
1	Male	12	6.4	C	17.6°	21.7°	+4.1°
2	Female	13	9.0	C	17°	16°	−1.0°
3	Female	11	5.6	C	14.4°	11°	−3.4°
4	Female	13	11.4	C	16.3°	6°	−10.3°
5	Female	11	7.4	C	13.2°	7.6°	−5.6°
6	Female	11	12.4	C	16.2°	20°	+3.8°
7	Male	11	9.2	C	12.5°	6°	−6.5°
8	Male	13	7.6	C	13.9°	12°	−1.9°
9	Female	12	8.9	C	17.2°	18°	+0.8°
10	Male	12	11.1	C	15°	9°	−6.0°
11	Male	12	11.2	S	17.5°, 15°	17°, 18°	−0.5°, +3.0°
12	Male	11	13.0	C	13.5°	14°	+0.5°
13	Male	12	13.4	C	15.8°	9.7°	−6.1°

(c) the effects of the 30-session sEMG biofeedback posture training program on the physical and mental domains of the health-related quality of life. The interview guide was developed by MCC and DL (Supplemental Appendix 2). Each interview lasted approximately 20 to 35 min, and the interviews were tape-recorded and transcribed verbatim into Chinese. Field notes were made during the interviews to facilitate probing and data analysis. To ensure that their opinions and comments were being transcribed precisely, the transcripts were reviewed by the early adolescents. The data analysis proceeded after they confirmed the accuracy of the content.

Data analysis

The interviews were analyzed by thematic analysis in line with the six analytical steps proposed by Braun and Clarke[44] with the qualitative software NVivo 10. The interview guide provided an initial structure for developing the codebook. Through reading each transcript multiple times, two authors (MCC and DL) achieved a thorough understanding of the interviews, they then extracted significant and meaningful statements and phrases to identify emergent patterns, labeled codes to data, and categorized the data into meaningful clusters representing the major themes and subthemes, with the aim of understanding the adolescents' subjective experiences with the sEMG biofeedback posture training. The themes and descriptions were then reviewed by the other authors (JY and JPYC) to ensure that detailed descriptions were included. An iterative process of reviewing and renaming the themes was carried out before the final themes were chosen (Figure 1).

The sample size was determined by data saturation when no further information relating to the themes emerged. After interviewing the 13 early adolescents with mild scoliosis who completed the sEMG biofeedback posture training program, the data collection stopped as data saturation was achieved and no repetitive information from the early adolescents was identified. The reporting of findings followed the checklist of consolidated criteria for reporting qualitative research (Supplemental Appendix 3).[45]

Results

Change in Cobb angle after the sEMG biofeedback posture training program

The average age of the early adolescents at the beginning of the training was 11.9 years (SD = 0.8), and the average duration of the whole training was 9.7 months (SD = 2.6). The Cobb angles of the early adolescents before (mean = 15.2°, SD = 1.6°) and after (mean = 13.0°, SD = 5.4°) the sEMG

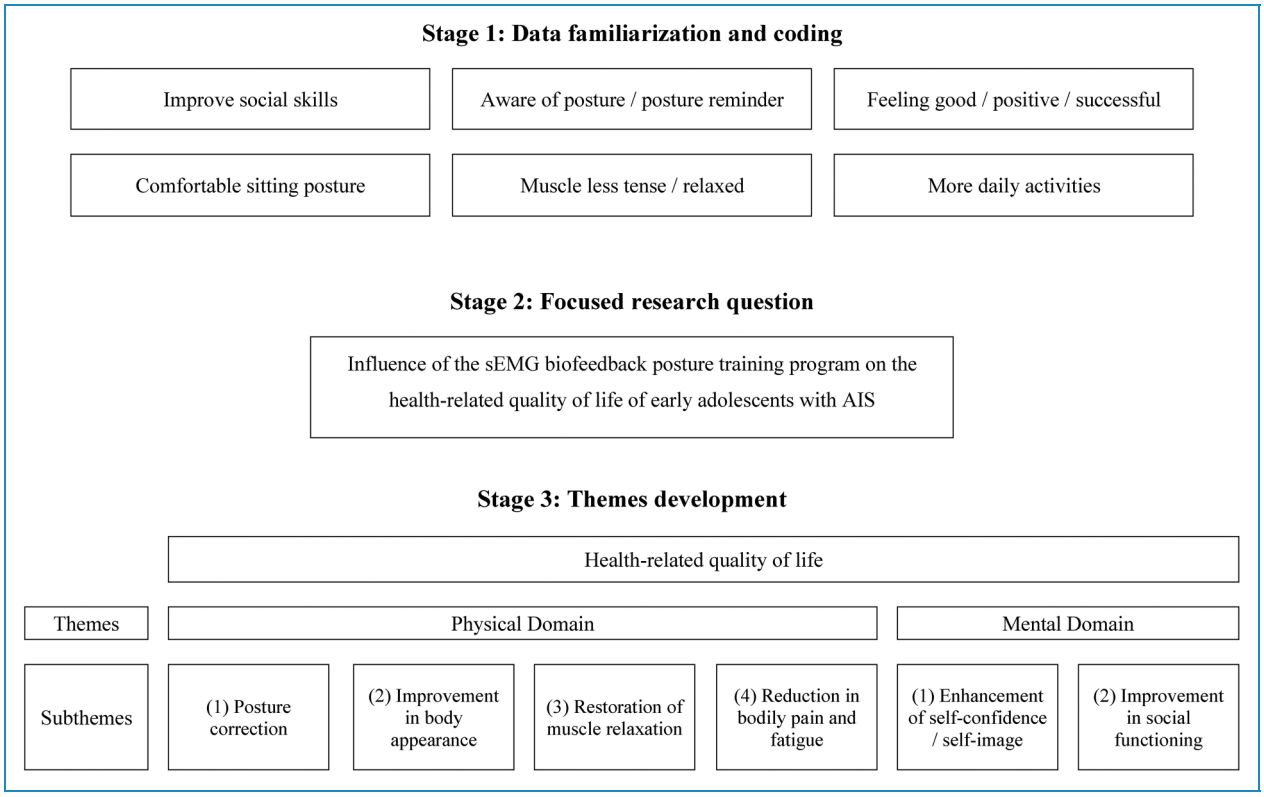

Figure 1. Development of the thematic analysis.

biofeedback posture training program are shown in Table 1. As evaluated by X-ray, their Cobb angles either decreased by at least 5° ($n = 5$) or showed minimal curve progression, with changes in the Cobb angle controlled under 5° ($n = 8$) after 30 sessions of the sEMG biofeedback posture training.

Changes in health-related quality of life after the sEMG biofeedback posture training program

The thematic analysis generated several subthemes related to the influence of spinal deformity and the effects of the sEMG biofeedback posture training program on the physical and mental domains of health-related quality of life. The subthemes under the physical domain included (a) posture correction, (b) improvement in body appearance, (c) restoration of muscle relaxation, and (d) reduction in bodily pain and fatigue. The subthemes under the mental domain included (a) enhancement of self-confidence/self-image and (b) improvement in social functioning. The quotes reported in this section were translated from the Chinese transcriptions into English.

Theme 1: Physical domain of health-related quality of life. (a) *Posture correction*. The sEMG biofeedback posture training enhanced the early adolescents' awareness of the proper posture when sitting and standing and of its significant influence on spinal curvature, which they neglected or overlooked before the training ($n = 7$). Though some of the adolescents ($n = 6$) shared that their parents often reminded them that an improper sitting posture might not be good for the growth of their spine and encouraged them to sit properly, they did not know how to correct it and were unaware of any adverse consequences. Once they were informed of the degree of their spinal curvature after an X-ray examination, they began to notice the negative impacts of an improper sitting posture over time. In particular, for the early adolescents whose Cobb angles were close to 20° ($n = 6$), they were apprehensive about receiving brace treatment if their spinal deformity was to become severe. As a result, the early adolescents were highly motivated to attend the sEMG biofeedback posture training program. They were conscious of their sitting posture during their daily activities, such as doing homework and attending classes. They corrected their improper sitting posture and restored it to maintain the trained posture immediately upon noticing the deviation. As the training lasted an average of 9.7 months, the early adolescents ($n = 12$) gradually sat properly and maintained the proper sitting posture as the habitual posture in their daily lives.

> The biofeedback posture training has extended my knowledge about the importance of sitting properly with a correct posture. I gradually see the difference in my sitting posture before, during, and after the training.

I often remind myself to pay attention to it during daily activities… my parents remind me less frequently as I have gradually developed the proper posture as habitual posture. (A1)

The (biofeedback) training taught me how to sit properly, and it becomes a habit in my daily life. (A5)

I have developed the habit of sitting properly in my daily activities… I often check my back to ensure that my spine does not protrude or is skewed to one side. If it happens, I am conscious to sit straight to ensure proper sitting posture. (A8)

(b) *Improvement in body appearance*. The early adolescents ($n = 7$) were very concerned about their body appearance and admitted that the spinal curvature had affected it. They acknowledged that their body appearance would be significantly adversely affected, such as having a hunchback and uneven shoulders if the spinal deformity became severe. They practiced very hard in their daily lives to maintain proper posture. After the training, the early adolescents ($n = 12$) expressed happiness that their spinal curvature was either reduced or minimally changed over time, as evidenced by X-ray examination. Therefore, they admitted that the sEMG biofeedback posture training was beneficial to them. In addition, given that they could maintain a proper upright posture after the training, they also shared that they became taller than before ($n = 5$), which was an impressive and significant outcome of the sEMG biofeedback posture training.

If I do not correct my spine curvature, my spine deformity will get worse to the extent that I look like an older adult. (A1)

The training helps me develop a charming body appearance. My spine curvature has improved. My spine looks straight, and most importantly, I am taller than before… so happy. I won't be short; I like to be tall. I become more charming after the training. (A7)

After the training, I can maintain an upright posture, won't give others a stealthy impression, like the witch in the fiction having hunchback, no such feeling now…in the past, my head always tilted forward. After the training, my back looks straight, won't feel odd in front of the mirror. (A8)

I keep checking my spine in a clinic regularly throughout biofeedback posture training. In the recent medical check-up, there was an improvement in my spine curvature after receiving the training for a while. I was very happy when they told me the result. (A11)

(c) *Restoration of muscle relaxation*. The early adolescents ($n = 12$) shared that they made lots of effort and used lots of energy to sit properly and maintain an upright position before the training. Gradually, their back muscles became very stiff and tense. When they relaxed their back muscles, many ($n = 10$) expressed having a hunchback, a tilted head, uneven shoulders, or a hip/pelvic tilt. During the sEMG biofeedback posture training, the early adolescents ($n = 12$) revealed that their self-awareness of their level of paraspinal muscle activities increased with the provision of animated indicators. Whenever they maintained the paraspinal muscle activities and the ratio of the muscle activities between the left and right sides of the four pairs of paraspinal muscles fell below the threshold of specific individualized requirements, thereby achieving the symmetry of the activities of the four pairs of paraspinal muscles and the relaxation of the paraspinal muscles, animated indicators appeared on the biofeedback screen. Therefore, based on this visual feedback, the early adolescents gradually learned how to relax the paraspinal muscles with an upright and proper sitting position. They could naturally maintain their posture with minimal effort after the training.

After the training, I feel more relaxed and "natural" of my back muscles when I walk. (A1)

After repeated training, I know to relax the back muscles. (A5)

I discovered that I should not be stressed to sit properly, should be very relaxed to sit properly…when I practice more, I do not feel anxious anymore. The training taught me how to relax. My muscles become relaxed too. (A8)

In the past, I don't know how to relax the muscles. I used much energy to hold my back muscles. It was so difficult to maintain… After the training, I do not have to use much energy and feel much relaxed (over upper back muscles). (A10)

I know how to control my back muscles to make them relaxed. (A13)

(d) *Reduction in bodily pain and fatigue*. Though they had a mild level of scoliosis, the early adolescents ($n = 5$) experienced different levels of bodily pain in their daily lives due to spinal deformity. They felt uncomfortable and quickly became fatigued after maintaining an improper posture. They were very frustrated, as they had to take a break to relieve themselves from the pain or they had to terminate their activities immediately. As the early adolescents did not know how to relax their muscles at the beginning of the training, they sometimes felt tired after the sEMG

biofeedback posture training. Once they gradually figured out how to use the visual feedback to correct their posture and relax the paraspinal muscles, they admitted that the training significantly reduced their bodily pain and muscle fatigue. Their vitality level also improved, so they could engage in their daily activities for a more extended period.

> The (biofeedback) training taught me how to sit properly… For example, I sit properly during classes, and my back muscles do not feel tired again since then. (A5)

> Due to scoliosis, I sometimes feel pain over the waist suddenly and tired easily…After the training, the pain is significantly reduced, which is experienced much less frequently than before. (A6)

> The training has lessened my bodily pain…I remember when I was playing with my friends in a park, my back felt painful suddenly… After the training, there is less degree of back pain. (A7)

> I was used to bending my waist forward while playing the piano. I lost my vitality quickly due to the uncomfortable sitting position and felt very tired at the end… After I learned how to sit upright naturally and relaxed, my back does not feel tired, and I have more vitality to keep playing the piano. (A8)

> The training is effective for my back pain. …I wished to sit upright and properly in the past, but I did not get used to it, so I felt very painful and uncomfortable over my back. After the training, I can sit upright with a correct sitting posture. I can sit for a longer period without feeling pain in my back…Moreover, my back muscles felt painful in the past when I ran. After the training, I do not have such pain anymore. (A10)

Theme 2: Mental domain of health-related quality of life. (a) *Enhancement of self-confidence/self-image*. Due to mild scoliosis and improper posture affecting body appearance, the early adolescents ($n = 5$) admitted to having a lack of confidence in front of others and to being worried about being noticed as having scoliosis. One early adolescent even expressed his anxiety when he stood in front of the mirror, as he was so concerned about his appearance. Therefore, the early adolescents admitted that they often felt inferior, shy, and hesitant to open up, which adversely affected their self-image. Given that the early adolescents observed improvements in the physical domain of their health-related quality of life during the sEMG biofeedback posture training, such as a reduction in spinal curvature and an improvement in body appearance, the early adolescents ($n = 6$) shared that they developed a sense of mastery and achievement as they actively participated in the training. In particular, many male adolescents ($n = 4$) felt satisfied with their improved body appearance, such as being taller and having their chest up, so their self-image was significantly enhanced, and they gained the confidence to interact with others.

> I have a sense of achievement. I feel happier when I observe the improvement of my spinal curvature. (A1)

> My self-image improves after the posture correction training, and now I gain more confidence. I was worried and scared that others might notice my spine deformity. Now, I feel relieved and do not worry about it. (A6)

> I feel satisfied and happy when seeing myself look taller after the training because I do not want to be a short guy. I like to be a tall guy…If I could meet my relatives who have not seen me often, they would see me look taller than before. This makes me feel confident in front of them. (A7)

> When sitting upright, I won't feel stealthy and become charming…The training improved my spine curvature, enhancing my self-image, so I have more self-confidence. I would be shy or scared to express my opinions in front of others. If you are hunched, you give the others an impression of low self-confidence and introverted, but if you hold your chest up and stand up straight, you will probably present a positive and confident vibe to others. (A8)

(b) *Improvement in social functioning*. During puberty, adolescents are in the stage of forming their own identity. They are very concerned about the feedback from their friends or significant others. They define themselves through social comparisons and turn to their close friends more than their family for advice and to share their feelings and concerns. Since the early adolescents with mild scoliosis were not satisfied with their body appearance and were always worried about whether their peers noticed their spinal deformity even though it was mild, some ($n = 5$) avoided interaction with their peers, which negatively affected their social functioning. After the sEMG biofeedback posture training, the early adolescents ($n = 5$) had an improved self-image and self-confidence due to the positive changes in the physical domain of their health-related quality of life. Their concerns about negative comments from their peers were diminished, so they were motivated to expand their social circle and were more willing to interact with others.

> Due to the negative perception of my spine, I was not eager to interact with people and afraid to approach them. When I went to school, I never said hi to my friends or others because I was afraid of them noticing my spine deformity.

I even ignored them when I was in school. Now I am willing to open myself and talk with them in school. (A6)

I am willing to take more initiatives to interact with others, share my opinions and feeling with them. (A8)

Discussion

As an extension of our previous pilot study,[28] this study recruited more early adolescents of both sexes to evaluate the benefits of 30-session sEMG biofeedback posture training in reducing spinal deformity or controlling curve progression and improving health-related quality of life. Given that the sEMG biofeedback posture training program was scheduled during the pandemic, the training program was suspended for a couple of weeks, or even months, when social distancing was restricted or when regular schooling was prohibited as a public health measure to reduce the transmission of COVID-19 in the community and to protect children and adolescents from infection. As a result, the duration of the whole training program was extended for some early adolescents, varying from 5.6 months to 13.4 months. Still, consistent with the findings of our previous pilot study,[28] the sEMG biofeedback posture training program either reduced the Cobb angle by at least 5° or controlled the curve progression under 5° over an average training duration of 9.7 months. The most significant change was found in an early female adolescent, whose Cobb angle reduced by 10.3°, as evidenced by X-ray examination after 30 sessions of the sEMG biofeedback posture training completed in 11.4 months. Therefore, the findings again demonstrate that the sEMG biofeedback posture training reduced or controlled the Cobb angle of early adolescents with mild scoliosis over time. In the future, it is also worthwhile investigating the long-term effects of sEMG biofeedback posture training to determine whether the reduction in the Cobb angle can be sustained over time after the training is completed.

Apart from the change in the Cobb angle, the sEMG biofeedback posture training program had similar training outcomes to PSSE[14–19]; for example, the early adolescents improved their health-related quality of life over time. Biofeedback training is a non-invasive intervention in which individuals are trained to improve their health and performance by monitoring the physiological signals from their bodies, such as their heart rate and muscle activities. Therefore, the sEMG biofeedback posture training program facilitates the active participation of early adolescents in the training sessions and increases their awareness of self-induced changes during neuromuscular re-education. Specifically, sEMG biofeedback training involves self-controlled training of muscle activity based on the constant biofeedback of sEMG signals recorded from a specific muscle, with the goal of muscle modification or re-education. Using visual feedback, the early adolescents with mild scoliosis gradually gained control over the physiological signals to relax and relieve pain and stress. In fact, biofeedback training has been used in clinical and research applications[46] to achieve muscle relaxation[47,48] or reduce muscle tension in adults.[49] In Hong Kong, early adolescents with mild scoliosis only require observation during follow-up through clinical monitoring and re-examination every six months until skeletal maturity.[50] Given the limited options of early intervention for adolescents with mild scoliosis, using sEMG biofeedback posture training may provide adolescents with mild scoliosis who are at risk of curve progression with an alternative early intervention to manage their spinal deformity. Even though some early adolescents only controlled the curve progression under 5° after 30 sessions of sEMG biofeedback posture training, they acknowledged the positive effects of the training on their health-related quality of life, as shared in their in-depth interviews. Therefore, the current findings further substantiate another benefit of sEMG biofeedback posture training, that is, the physical and mental health of the early adolescents was enhanced after the training. To provide a more comprehensive picture of the training outcomes of sEMG biofeedback posture training, the findings from the in-depth interviews will be integrated with the results from the standardized questionnaire used in the quantitative research of this study. At the same time, the association between the changes in the Cobb angle and the symmetry of paraspinal muscle activities after sEMG biofeedback posture training will be explored in future studies.

Given that the early adolescents had to attend 30 training sessions, engaging in the repeated practice of posture correction and muscle relaxation for an average duration of 9.7 months, it is undoubted that they were highly motivated. As most of them, mainly the male early adolescents, attended the training alone after school, they revealed that their compliance was mainly due to their motivation to improve their spinal deformity, even though their level of scoliosis was mild, with their primary goal being to either reduce or control further curve progression over time. Moreover, since having a better-looking appearance was crucial to the early adolescents, they tried their best to comply with the sEMG biofeedback posture training. As shared by some of the adolescents, the whole training lasted so long that they regarded it as their regular activity after school or that it became part of their daily activities. They did not attend an X-ray examination to evaluate any change in their Cobb angle until they had completed the 30 sessions of sEMG biofeedback posture training. Therefore, the gradual improvement of their health-related quality of life they experienced over time positively reinforced their continued active engagement in the training and their compliance with training to strive for better

training outcomes. In addition, sEMG biofeedback posture training enables early adolescents to be in charge of the training process. Given that patient participation and involvement in the treatment have positive effects on the process and rehabilitation outcomes,[51,52] sEMG biofeedback posture training improves early adolescents' psychological well-being by empowering their autonomy in the management of their health. According to the International Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment 2005 consensus paper, quality of life, psychological well-being, back pain, and Cobb angle are included in the list of the most general goals of the conservative treatment of AIS.[1] Our findings suggest that sEMG biofeedback posture training has the potential to achieve these goals for early adolescents with mild scoliosis.

Strengths and limitations

The effects of sEMG biofeedback posture training should be considered in light of the following limitations. First, the sample size in this qualitative study was limited. The training duration varied from 5.6 months to 13.4 months and some early adolescents did not have consistent training once per week. Therefore, it cannot rule out the possibility that the change in the Cobb angle may be affected by factors such as age, gender, training duration, and the natural course of AIS over time. Hence, it is still difficult to confirm the effectiveness of the training and to generalize its results. It should be further investigated with a larger sample using randomized controlled trials to compare with other early interventions. Second, most of the adolescents ($n = 12$) had a single curve (i.e. a C curve), while only one suffered from a double curve (i.e. an S curve). Therefore, it is conceivable that sEMG biofeedback posture training may be more beneficial for early adolescents with a single curve, and it is worthwhile exploring the underlying mechanism. Third, to date, the etiopathogenesis of AIS is still unclear, and the causes are considered to be multifactorial. A recent systematic review found that proprioceptive deficits occur in AIS.[53] Since sEMG biofeedback posture training relies on the physiological signals of muscle activities to relax, it is conceivable that proprioceptive signals from the paraspinal muscles may be altered after training. Although it is still unknown whether proprioceptive deficits are predisposing factors for AIS or secondary to AIS, it is worthwhile investigating whether sEMG biofeedback posture training is associated with changes in the proprioceptive responses in AIS. Fourth, as the training modules were similar in every session, some of the early adolescents expressed their feedback during the in-depth interviews to make the training more attractive. As shown in the previous study regarding brace treatment, co-designing a brace with adolescents and concerning the aesthetic aspects of the surface design of the brace induced positive subjective experiences in adolescents, addressing their psychological issues during treatment and increasing user compliance.[54] Therefore, co-design of the animated indicators on the biofeedback screen by using their favorite video tracks can be considered to further enhance their motivation to comply with the training and to sustain their interest and attention during the training. Finally, the early adolescents who were interviewed were highly motivated, complied with the training, and completed 30 sessions of the sEMG biofeedback posture training program. Their commitment may contribute to the risk of bias in their subjective experiences. Therefore, the sEMG biofeedback posture training program may be more suitable for early adolescents who are proactive and eager to improve their health.

Conclusions

The 30-session sEMG biofeedback posture training reduced or controlled the Cobb angle of early adolescents with mild scoliosis over time. Five early adolescents showed a reduction in their spinal curvature Cobb angles by at least 5°, while eight early adolescents showed a minimal curve progression, with changes in the Cobb angle controlled under 5°. In addition, they acknowledged that the sEMG biofeedback posture training program improved the physical and mental domains of their health-related quality of life, resulting in (a) posture correction, (b) an improvement in body appearance, (c) the restoration of muscle relaxation, (d) a reduction in bodily pain and fatigue, (e) the enhancement of self-confidence/self-image, and (f) an improvement in social functioning. Given its positive effects, the sEMG biofeedback posture training program has the potential to be an alternative early intervention for early adolescents with mild scoliosis, and further empirical studies need to be carried out in order to substantiate its effectiveness and to evaluate the sustainability of its benefits over time.

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